Probing High-Column Outflows in BALQSOs Using Metastable Helium

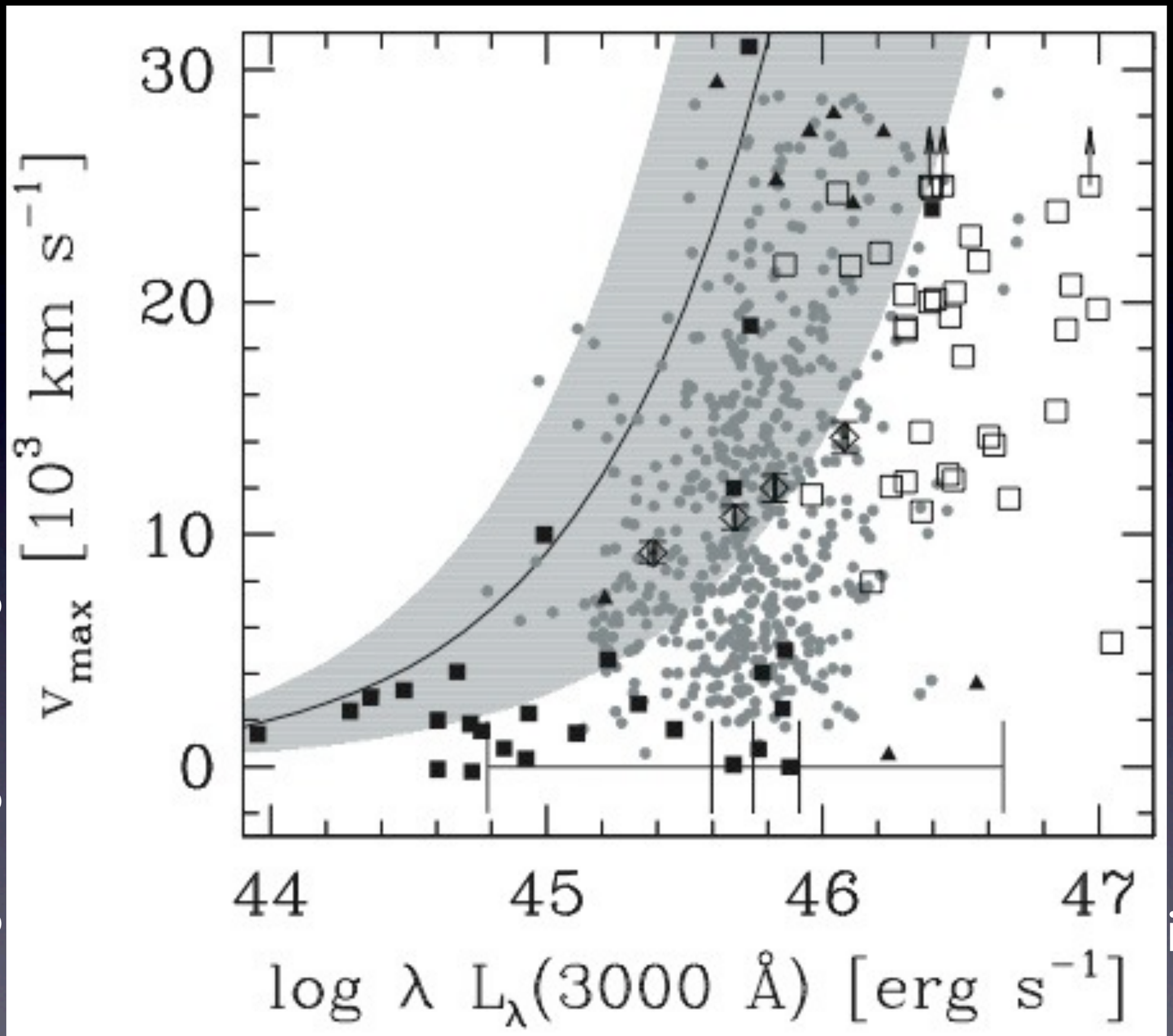
Karen M. Leighly (OU)
Matthias Dietrich (OSU)
Don Terndrup (NSF/OSU)
Sarah Gallagher (UWO)
Adrian Lucy (OU)

BALQSOs: What do we want to know?

- Outflow acceleration mechanism (radiative line driving, hydromagnetic,.....)
- Mass flux / Kinetic energy (feedback)
- Geometry of the outflow (unification; outflow physics, e.g., confinement)

BALQSOs: What can we measure?

- V_{max} ➠ acceleration mechanism diagnostic (Laor & Brandt 2002; Ganguly et al. 2007)
- ΔV, i.e., BALs, miniBALs, NALs ➠ geometry (Gallagher et al. 2006; Gibson et al. 2009)
- Column density ➠ kinetic energy/luminosity
- Covering fraction ➠ geometry, outflow physics



ics

BALQSOs: What can we measure?

- V_{max} ➠ acceleration mechanism diagnostic (Laor & Brandt 2002; Ganguly et al. 2007)
- ΔV, i.e., BALs, miniBALs, NALs ➠ geometry (Gallagher et al. 2006; Gibson et al. 2009)
- Column density ➠ kinetic energy/luminosity
- Covering fraction ➠ geometry, outflow physics

BALQSOs: What can we measure?

- V_{max} ➠ acceleration mechanism diagnostic (Laor & Brandt 2002; Ganguly et al. 2007)
- ΔV, i.e., BALs, miniBALs, NALs ➠ geometry (Gallagher et al. 2006; Gibson et al. 2009)

?{

- Column density ➠ kinetic energy/luminosity
- Covering fraction ➠ geometry, outflow physics

But there is a way....

But there is a way....

- Rare ions ➠ not saturated

But there is a way....

- Rare ions ➠ not saturated
- Two transitions from the same level

But there is a way....

- Rare ions ➠ not saturated
- Two transitions from the same level
- ➠ Relative optical depths fixed by atomic physics

But there is a way....

- Rare ions ➠ not saturated
- Two transitions from the same level
- ➠ Relative optical depths fixed by atomic physics
- Two equations, two unknowns ➠ solve for true optical depth and covering fraction

Previous Work

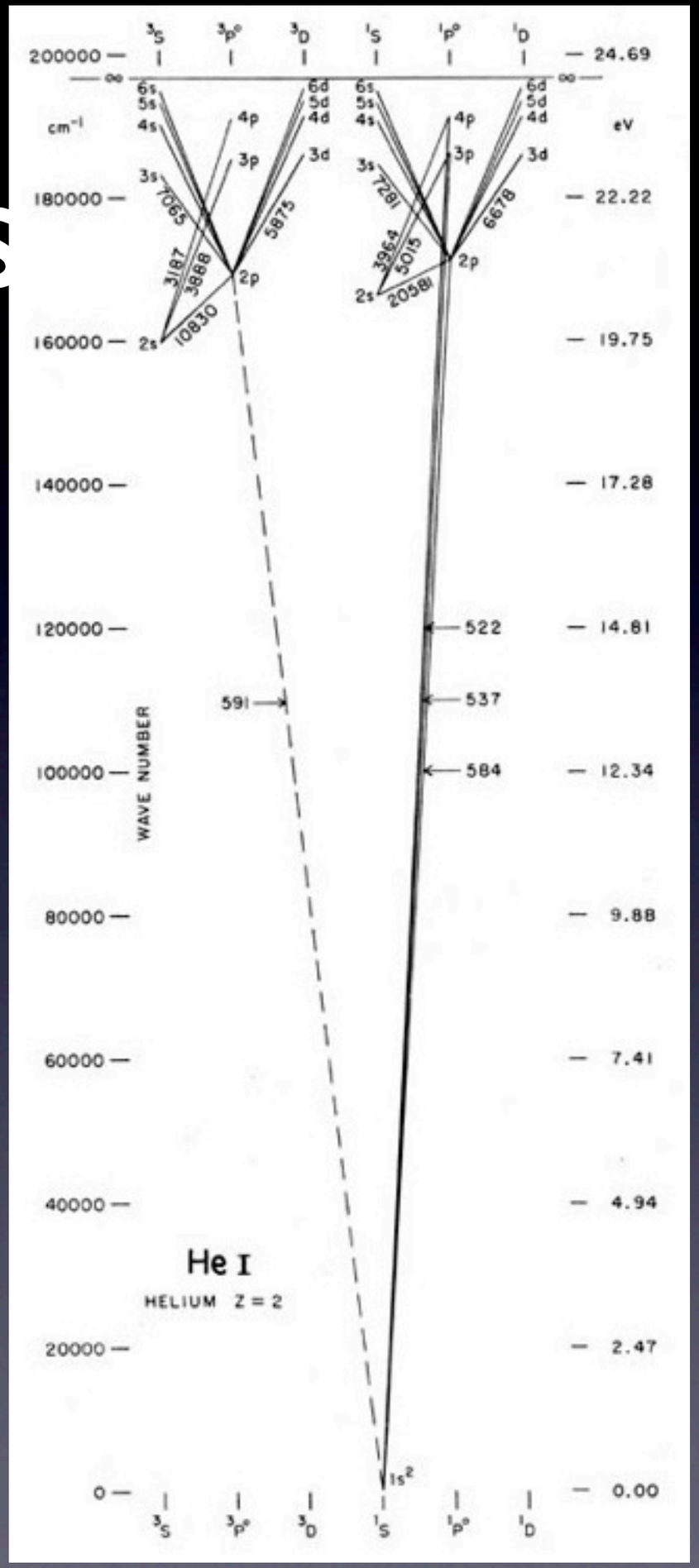
- Arav et al. - SiII, FeII (also, transitions from ground and excited states yield density)
- Hamann et al. - PV 1118,1128
  - Phosphorus abundance is ~765 times lower than carbon

We propose HeI*

- Populated by recombination from He^+
- Depopulated by collisions: $HeI^*/He^+ \sim 5.8 \times 10^{-6}\ f(T,n_e)$
- Metastable triplet 2s state acts as a second ground state (decay time 2.2 hours)
- ➠*measures He+ column*

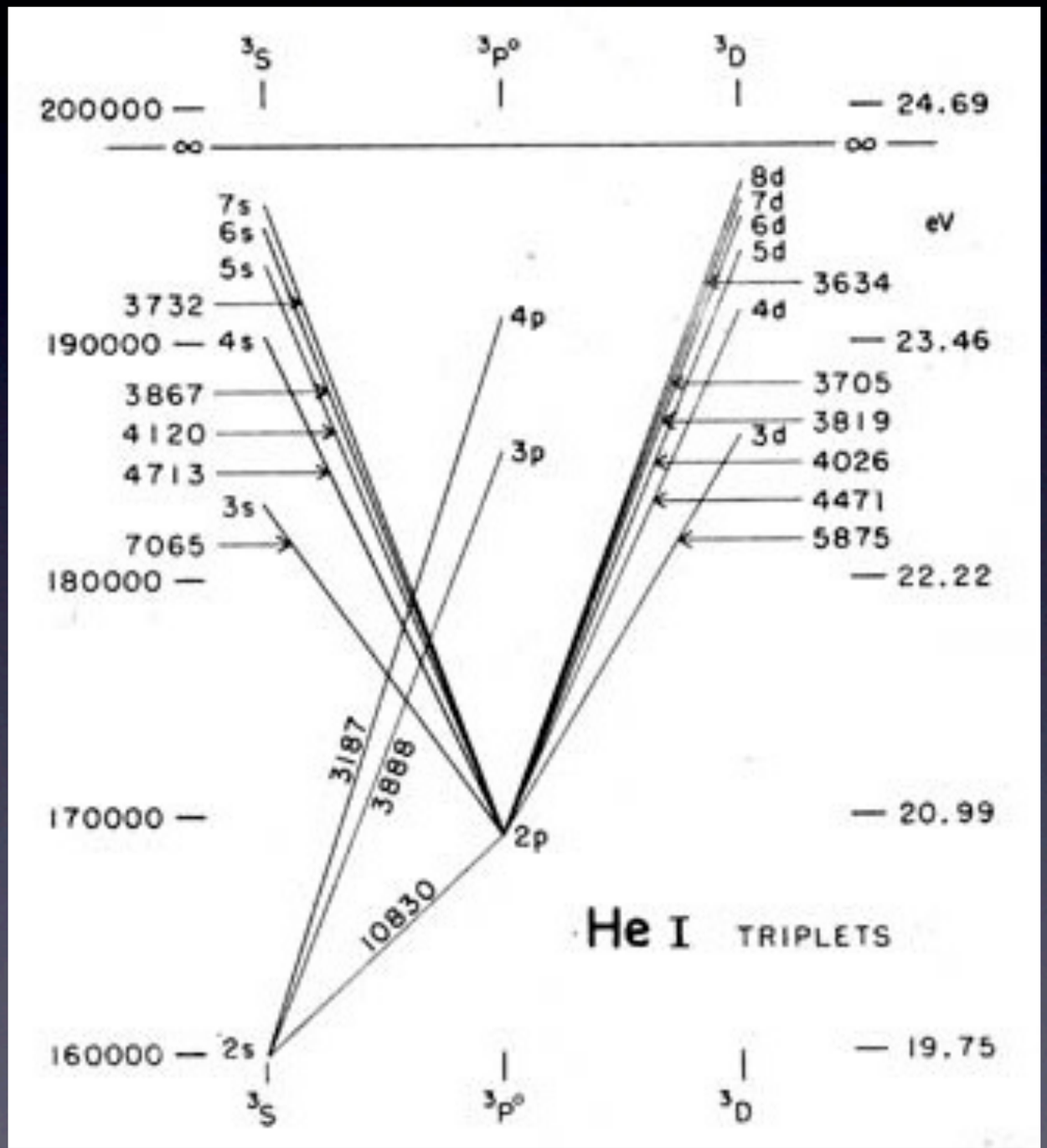
We propos

- Populated by recombination from He^+
- Depopulated by collisions: $HeI^*/He^+ \sim 5.8 \times 10^{-6} f(T, n_e)$
- Metastable triplet 2s state acts as a second ground state (decay time 2.2 hours)
- ➠*measures He+ column*



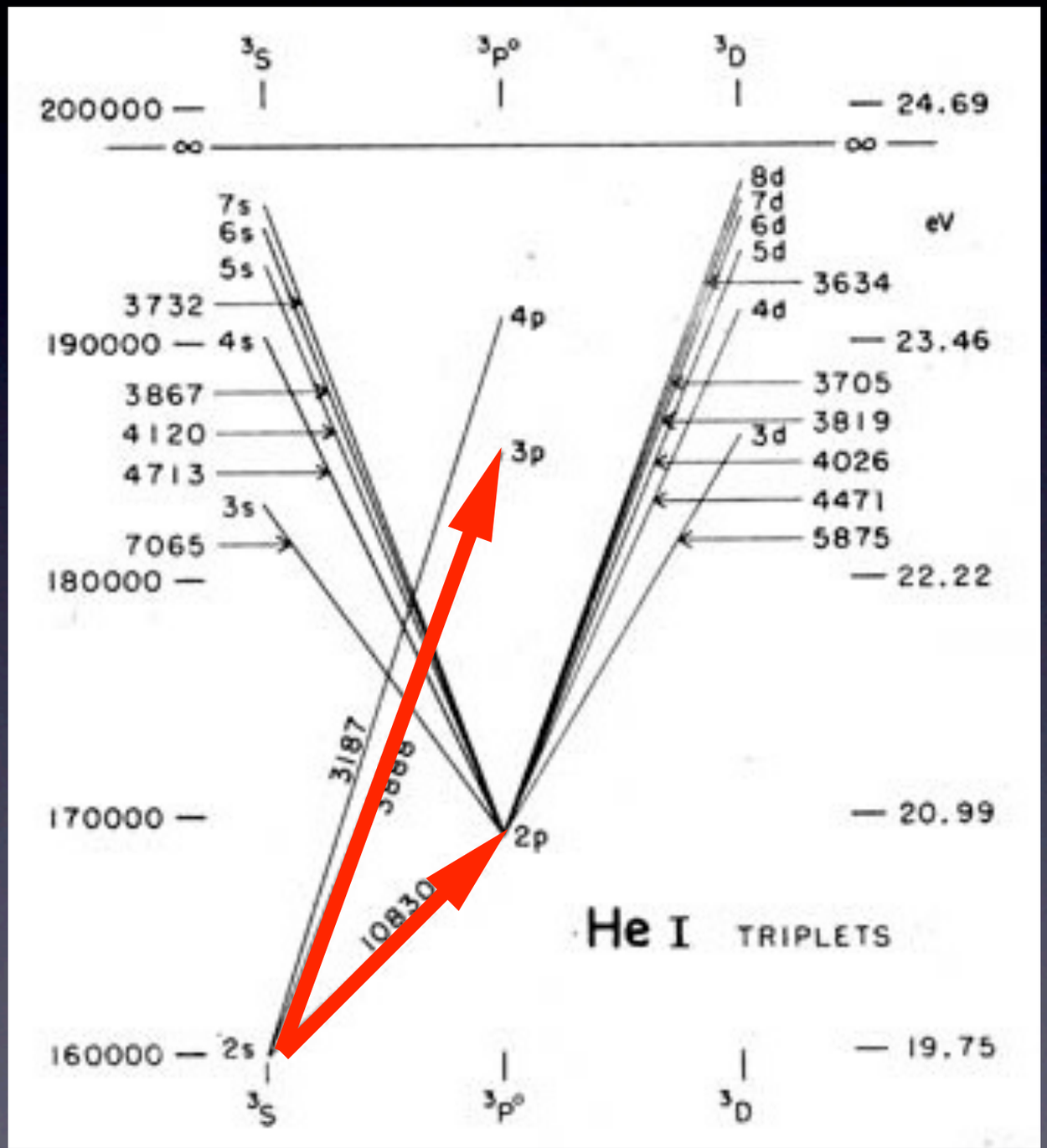
We propose HeI*

- Populated by recombination from He^+
- Depopulated by collisions: $HeI^*/He^+ \sim 5.8 \times 10^{-6}\ f(T, n_e)$
- Metastable triplet 2s state acts as a second ground state (decay time 2.2 hours)
- ➠*measures He+ column*



We propose HeI*

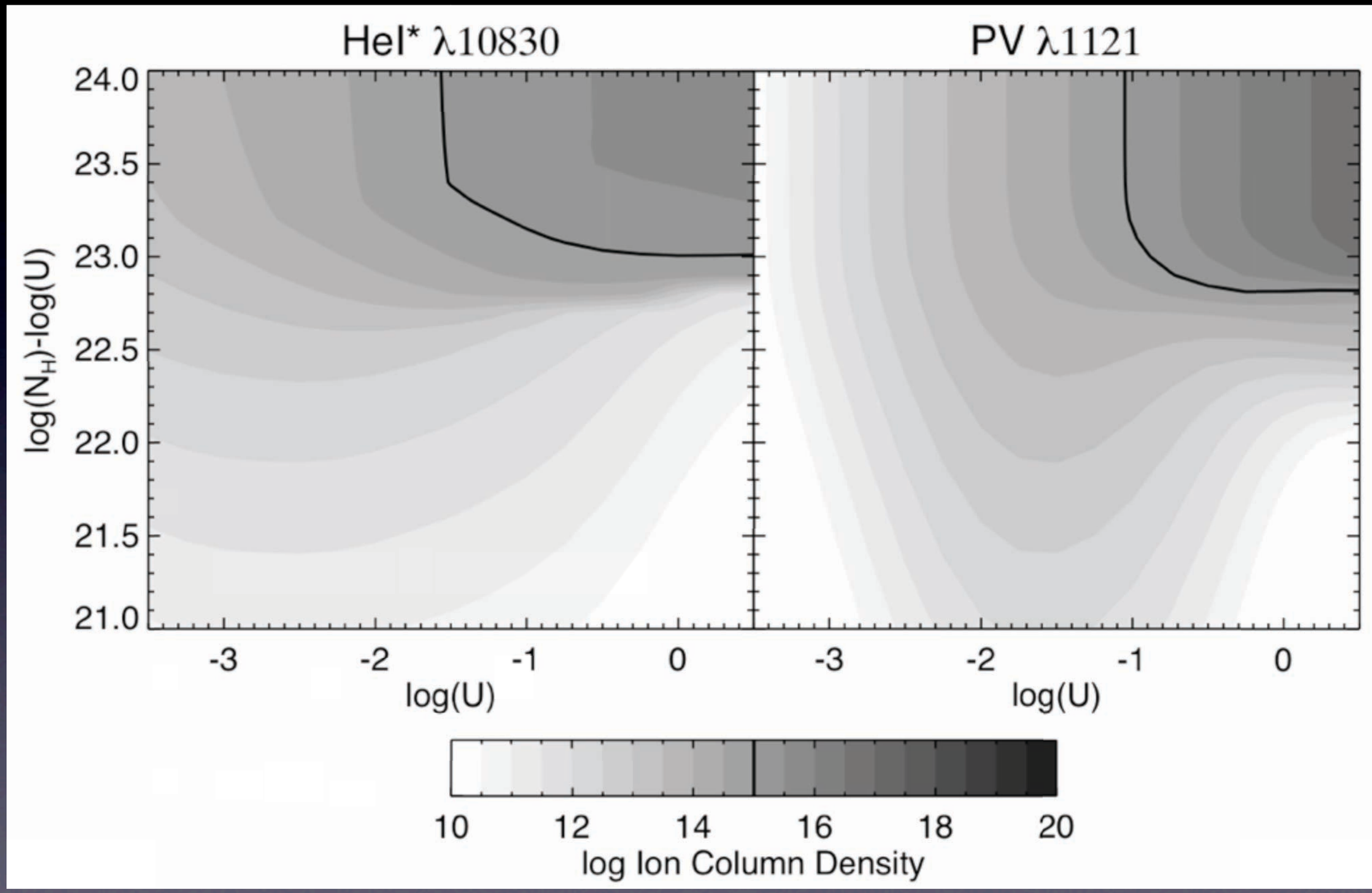
- Populated by recombination from He^+
- Depopulated by collisions: $HeI^*/He^+ \sim 5.8 \times 10^{-6}\ f(T, n_e)$
- Metastable triplet 2s state acts as a second ground state (decay time 2.2 hours)
- ➠*measures He+ column*



HeI* vs P^{+4}

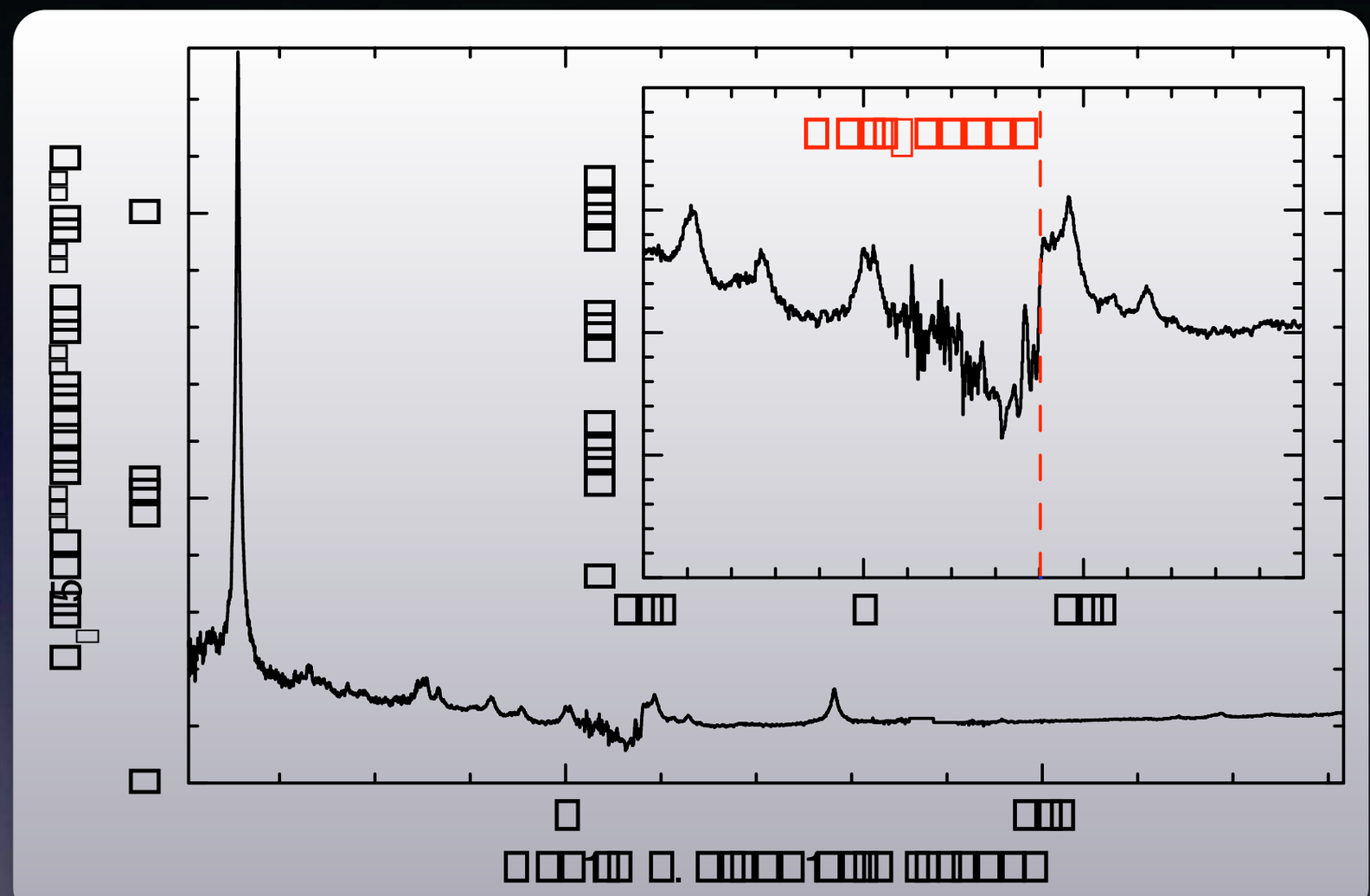
$$\tau(v) = \frac{\pi e^2}{m_e c} f\lambda N(v) = 2.654 \times 10^{-15} f\lambda N(v)$$

- Resonance lines: ~0.1 < f < ~1.0, ~1000<λ<~10000
- For τ(v)~1, Δv ~10,000 km/s
- ⇒ N_{ion}~14.5-16.0


HeI* λ10830
PV λ1121
log(N_H)-log(U)
24.0
23.5
23.0
22.5
22.0
21.5
21.0
-3
-2
-1
0
log(U)
log(U)
10
12
14
16
18
20
log Ion Column Density

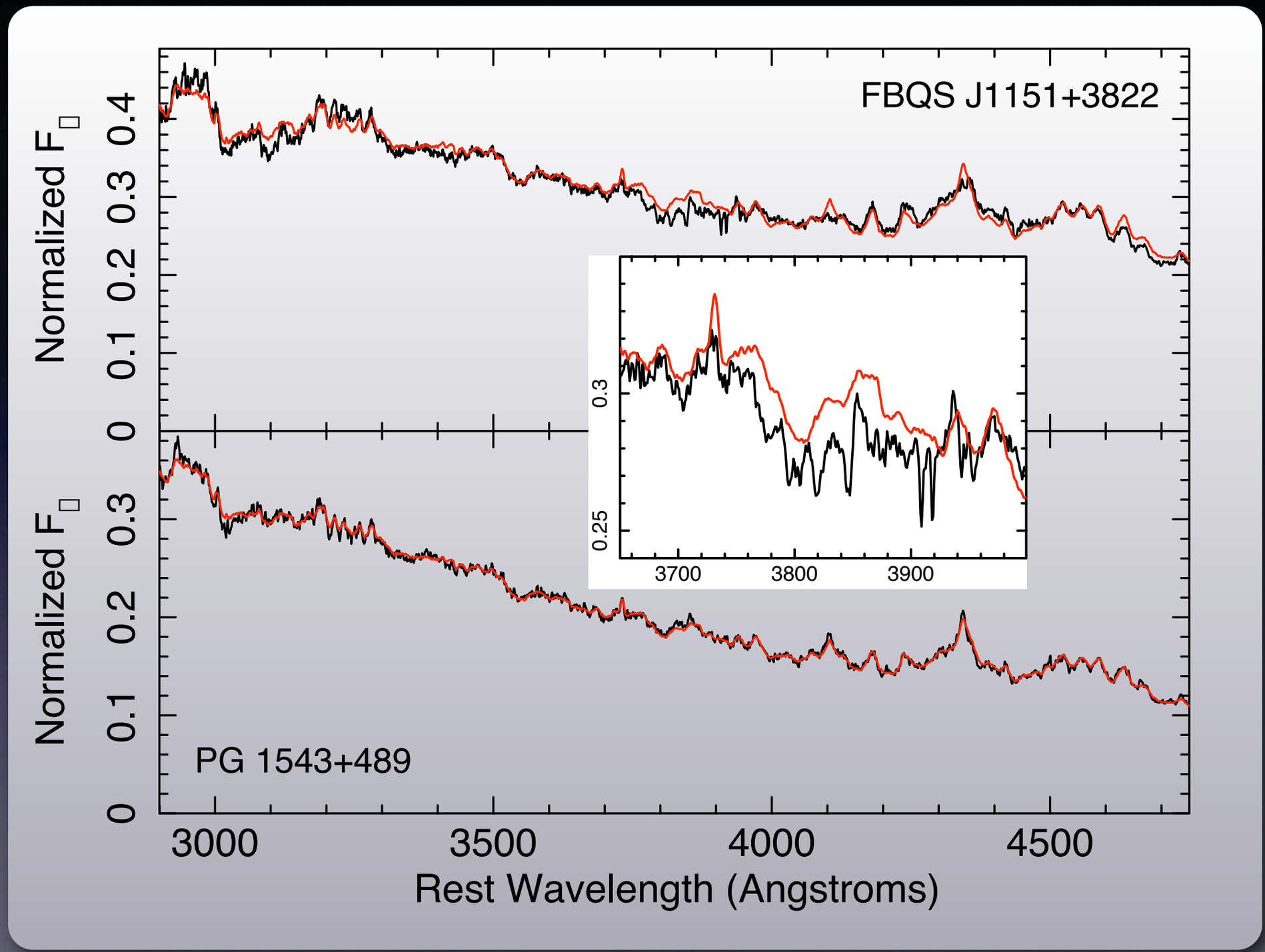
FBQS J1151+3882

- Observed using SpeX on IRTF
- First HeI*10830 BALQSO



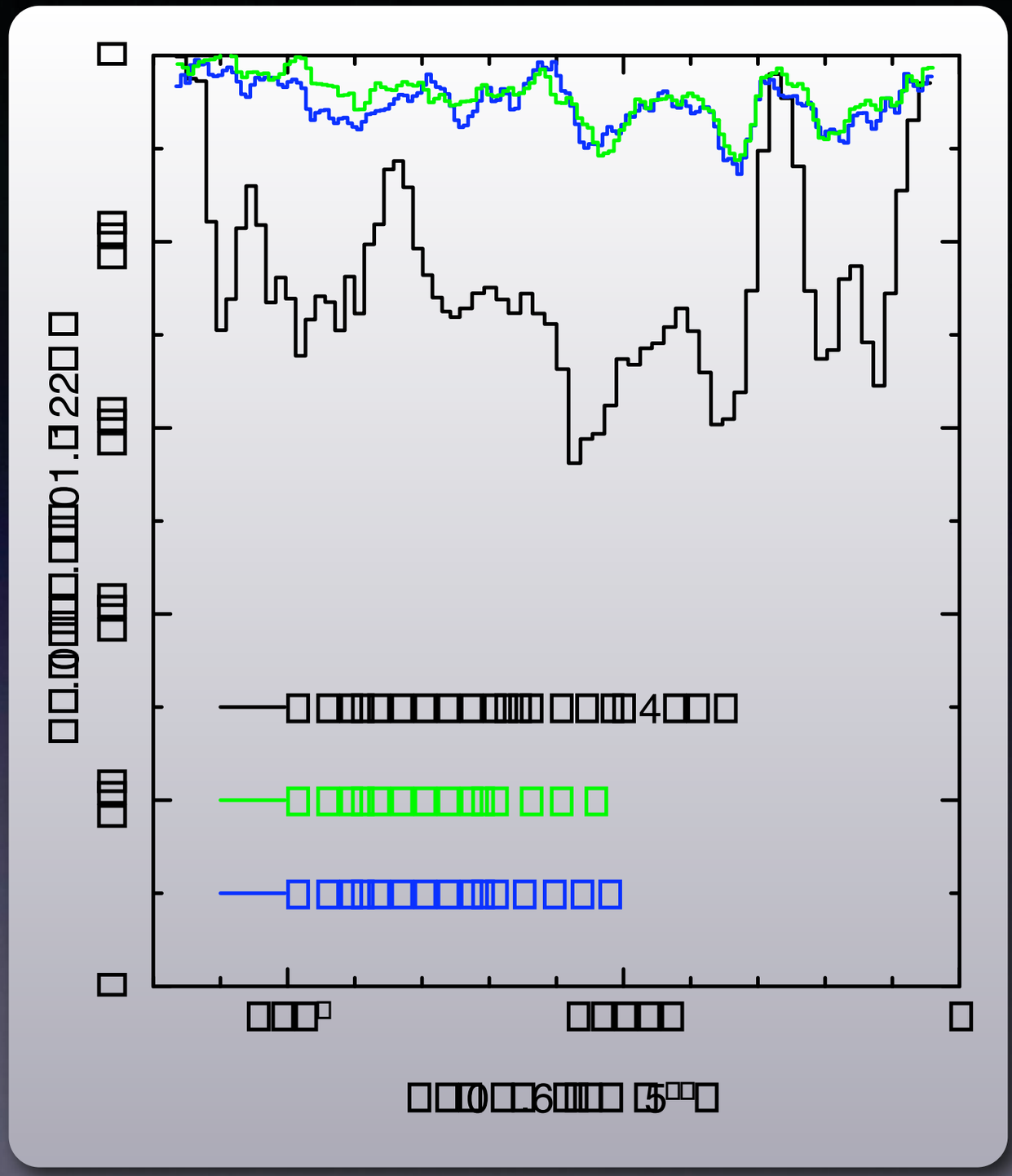
Leighly et al. 2011

HeI* 3889 is present too

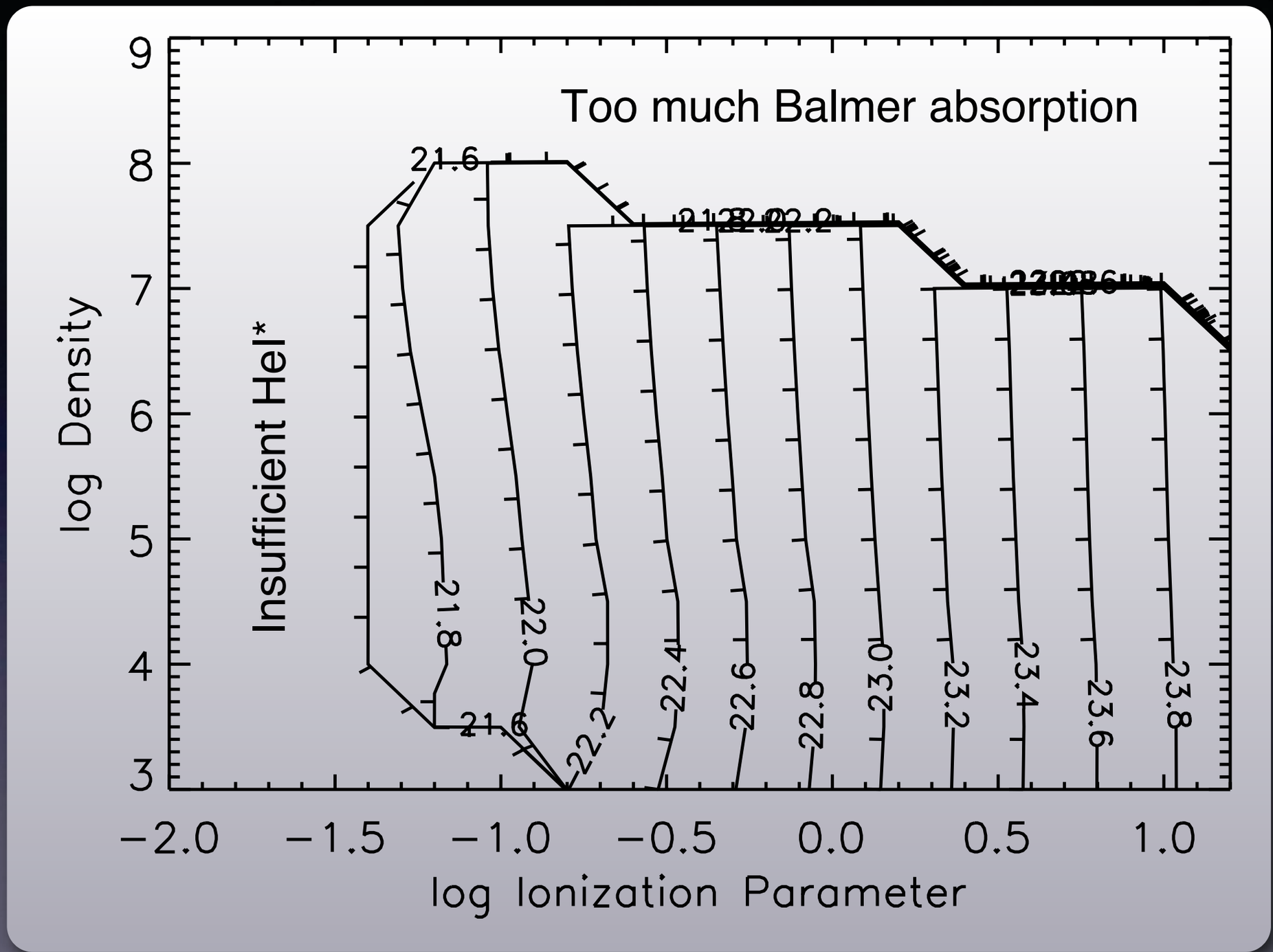


Partial Covering Analysis

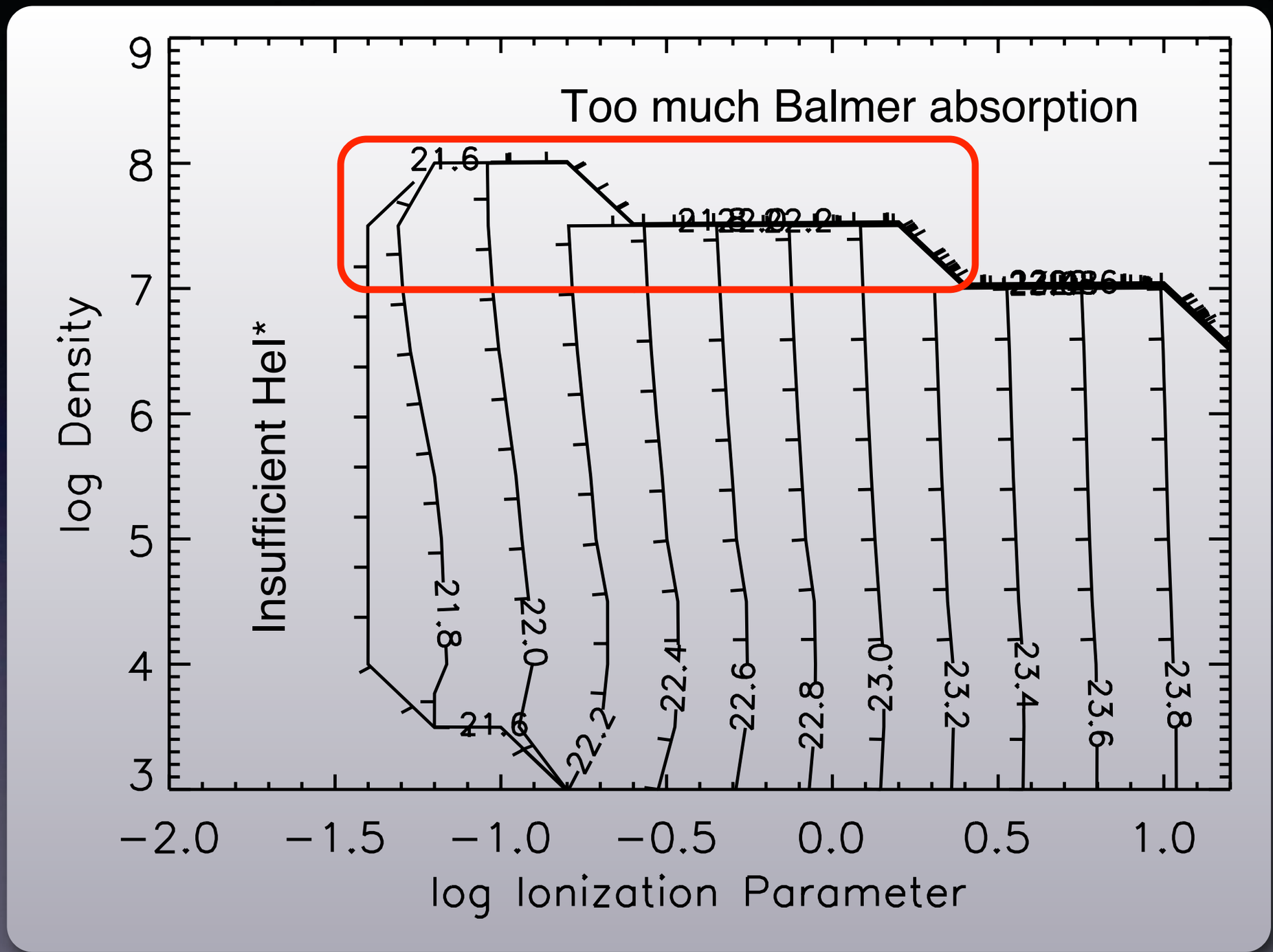
- Solve for f_{cov} and optical depth as a function of velocity
- Mean covering fraction ~0.2
- log Average HeI* column ~14.9



Cloudy Analysis

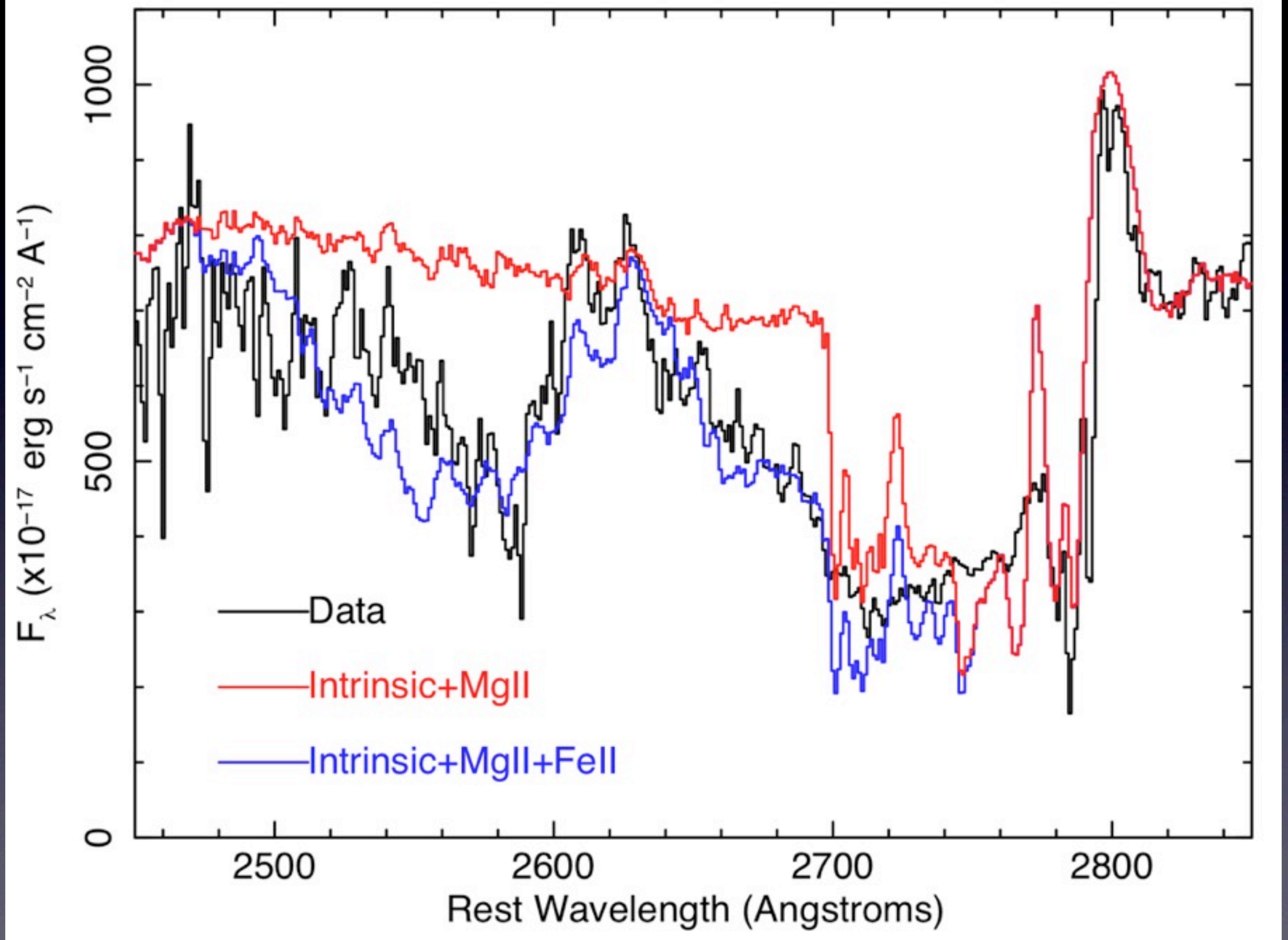


Cloudy Analysis



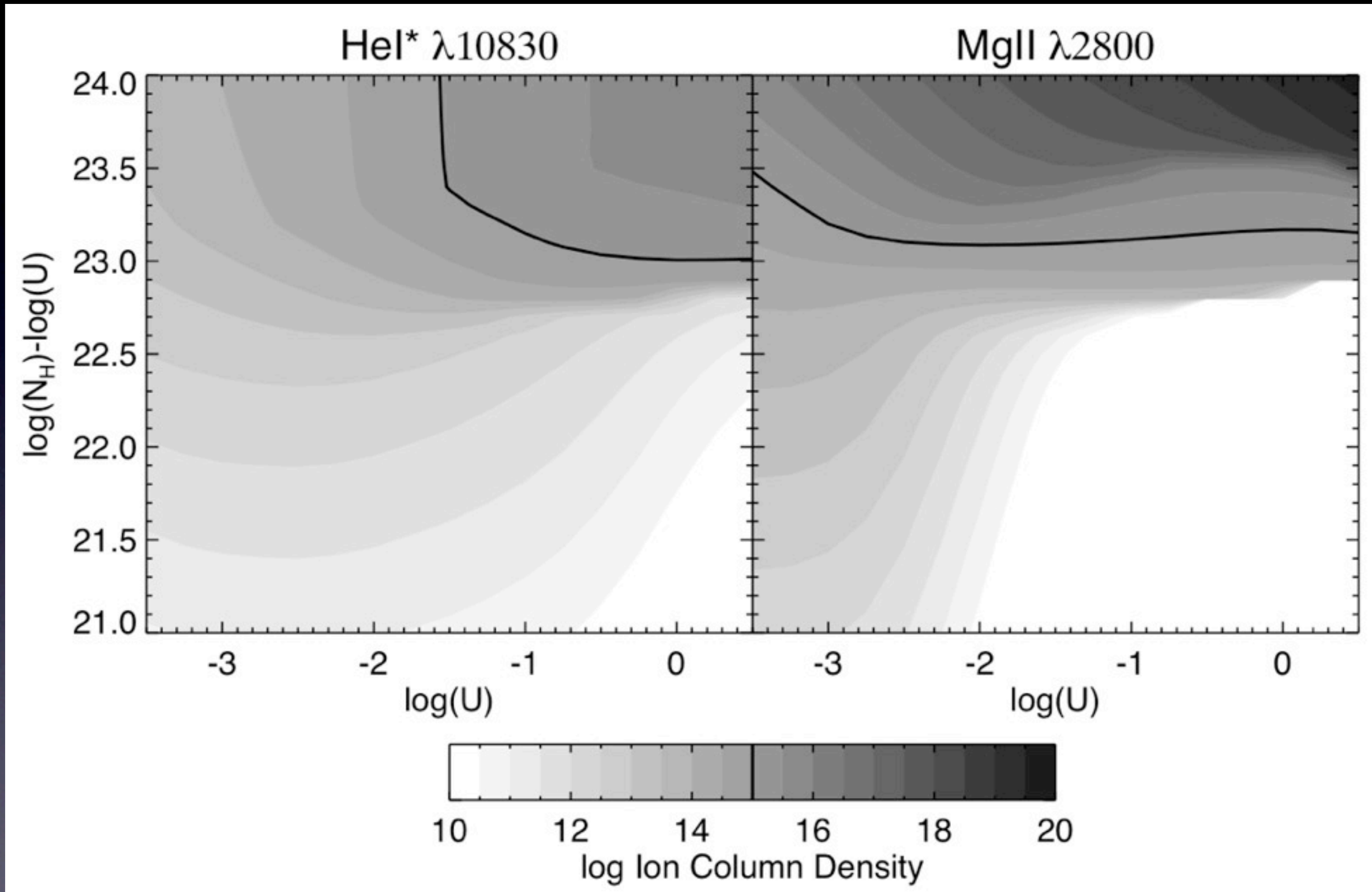
New Observation of MgII

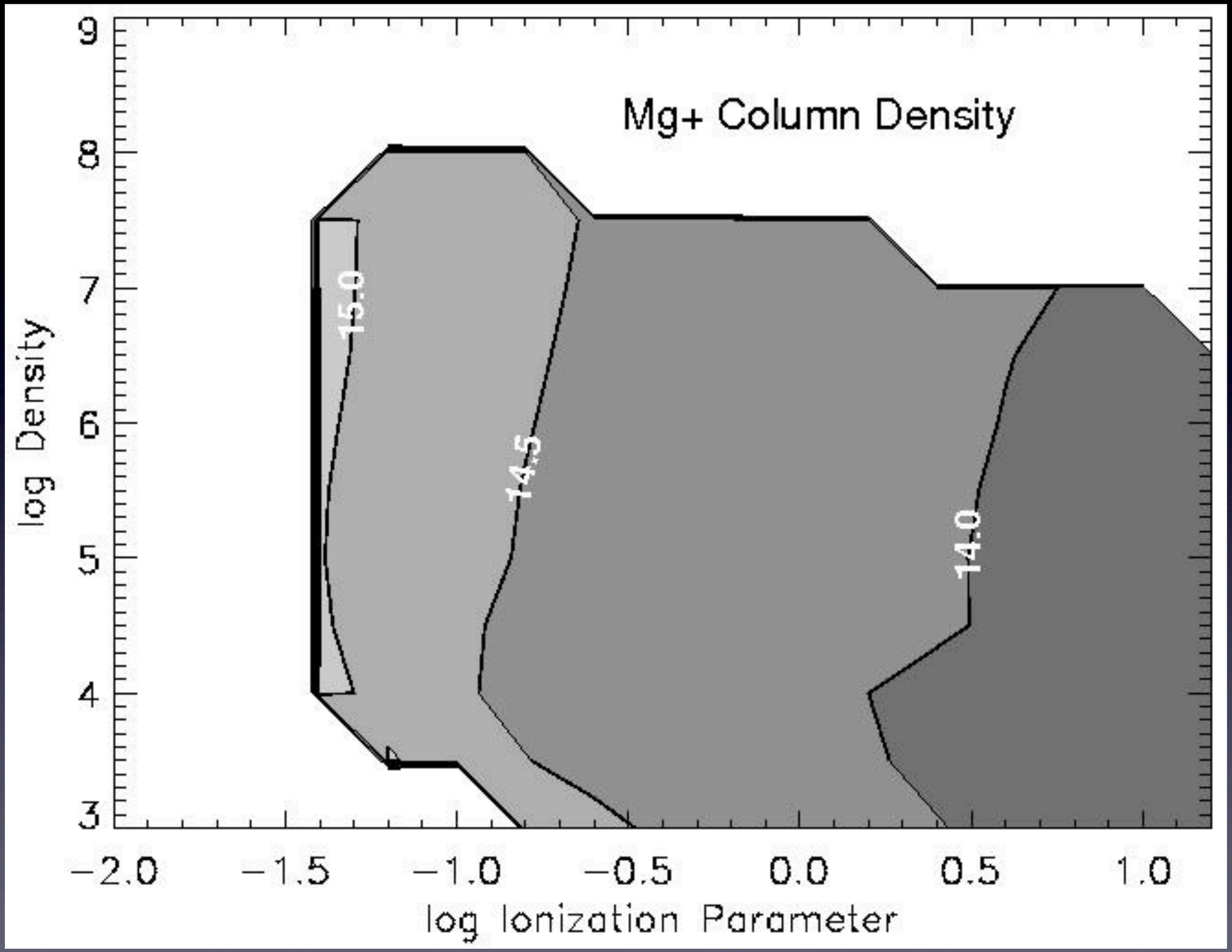
- Observed at KPNO May 2011
- Analyzed by Adrian Lucy (preliminary - see AAS poster)
- ⇒FBQS J1151+3822 is an FeLoBAL
- log Mg+ column density ~ 15


1000
500
0
F_λ (x10^{-17} erg s^{-1} cm^{-2} A^{-1})
Data
Intrinsic+MgII
Intrinsic+MgII+FeII
2500
2600
2700
2800
Rest Wavelength (Angstroms)

New Observation of MgII

- Observed at KPNO May 2011
- Analyzed by Adrian Lucy (preliminary - see AAS poster)
- ⇒FBQS J1151+3822 is an FeLoBAL
- log Mg+ column density ~ 15


HeI* λ10830
MgII λ2800
log(N_H)-log(U)
24.0
23.5
23.0
22.5
22.0
21.5
21.0
-3
-2
-1
0
log(U)
log(U)
10
12
14
16
18
20
log Ion Column Density

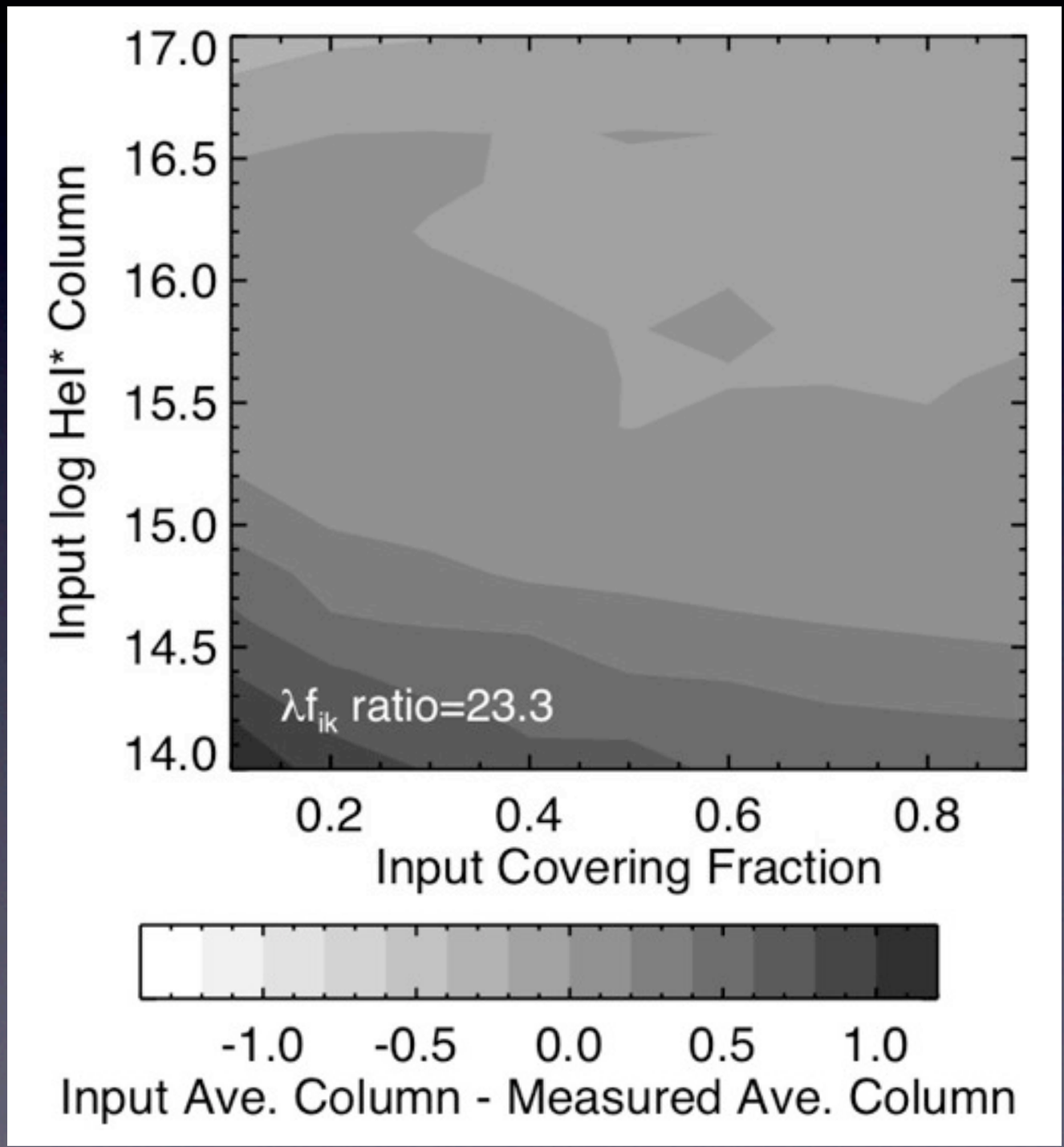

Mg+ Column Density
15.0
14.5
14.0
log Density
9
8
7
6
5
4
3
−2.0
−1.5
−1.0
−0.5
0.0
0.5
1.0
log Ionization Parameter

Results for FBQS J1151+3822

- Assuming radiative line driving:
  - log N_H = 21.7-21.9
  - Radius = 5-18 parsecs
    - mass outflow rate = 11-34 solar masses/yr
    - log Kinetic luminosity = 44-44.5
    - Kinetic luminosity is 0.2-0.6% bolometric
- ➠ Relatively high-column, powerful outflow originating relatively close to the central engine

HeI* Advantages

- Can be observed from the ground in *low-z* objects
- Blending is not a problem
- Sensitive to high columns



Followup

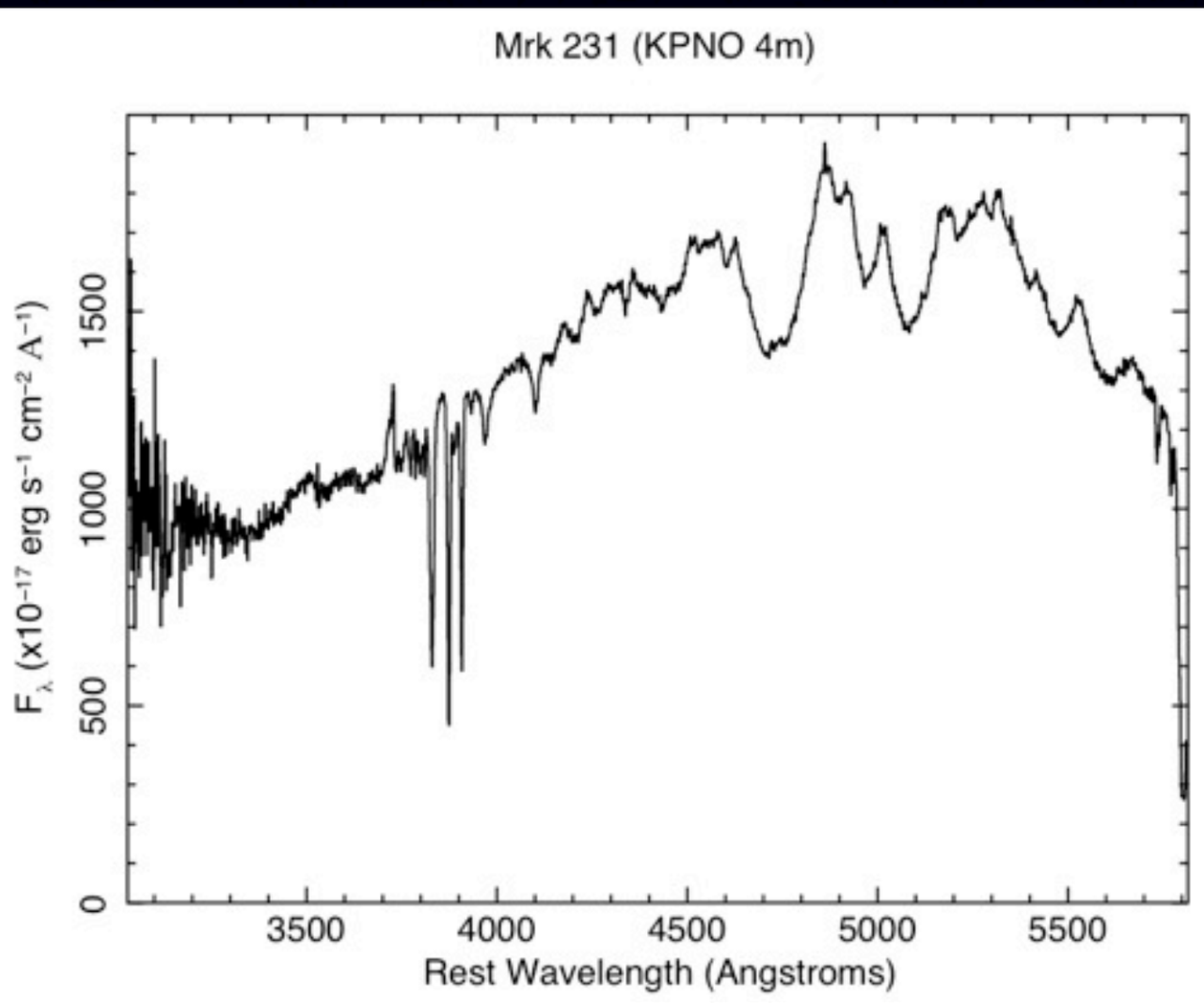
Followup

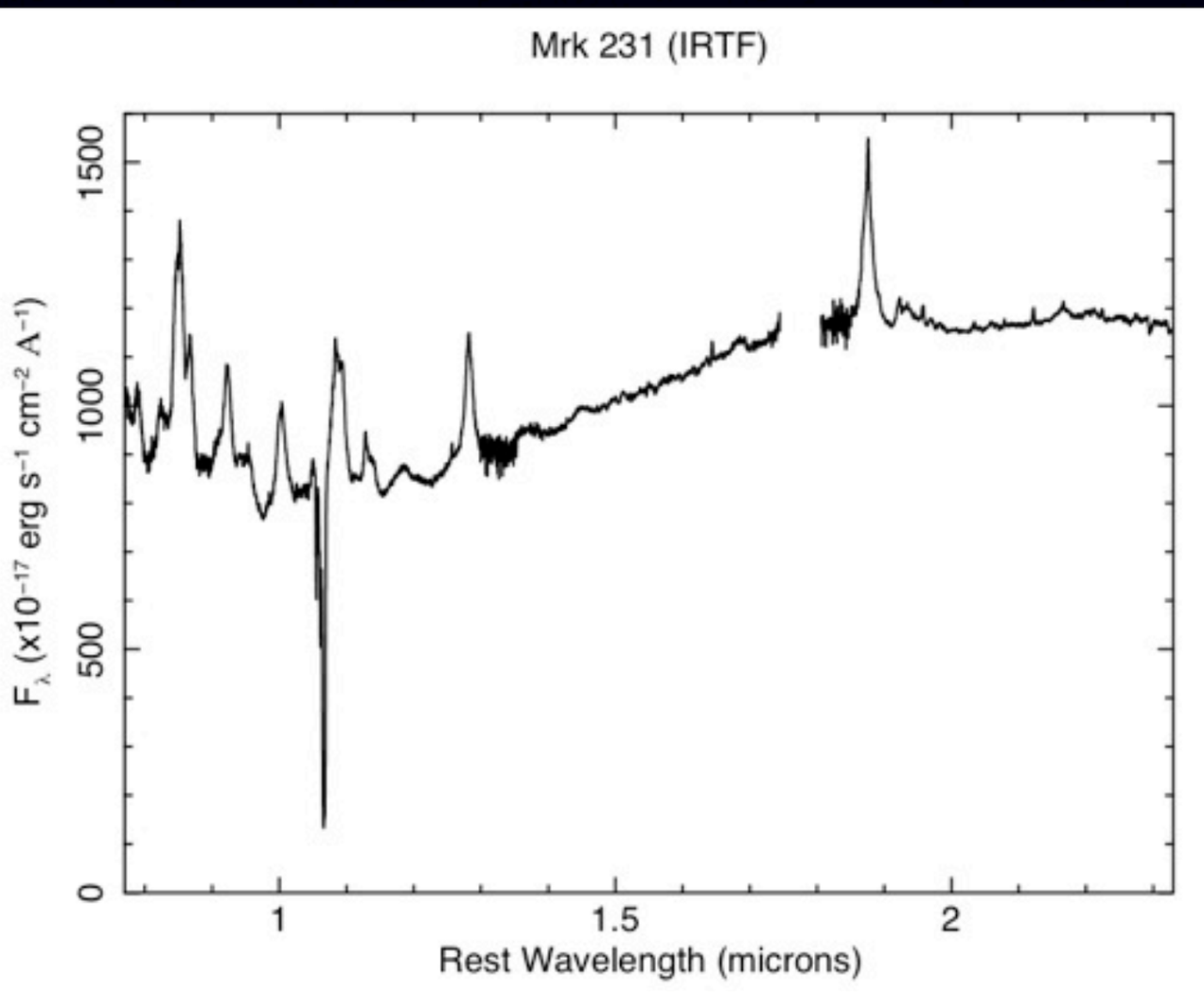
- Low Redshift BALQSOs
- 14 objects, most with known CIV absorption
- Observed using IRTF SpeX and MDM 2.4m CCDS

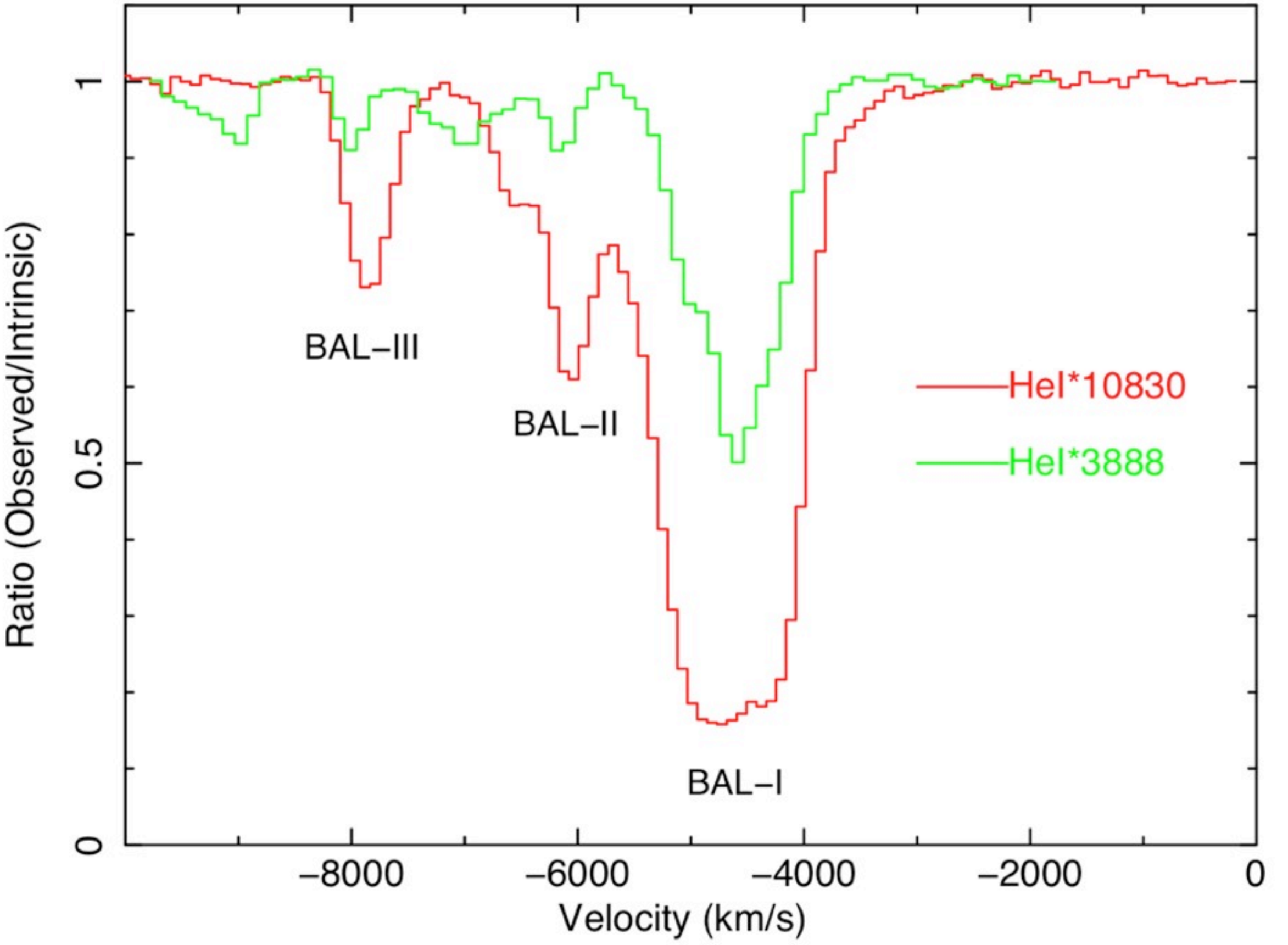
Followup

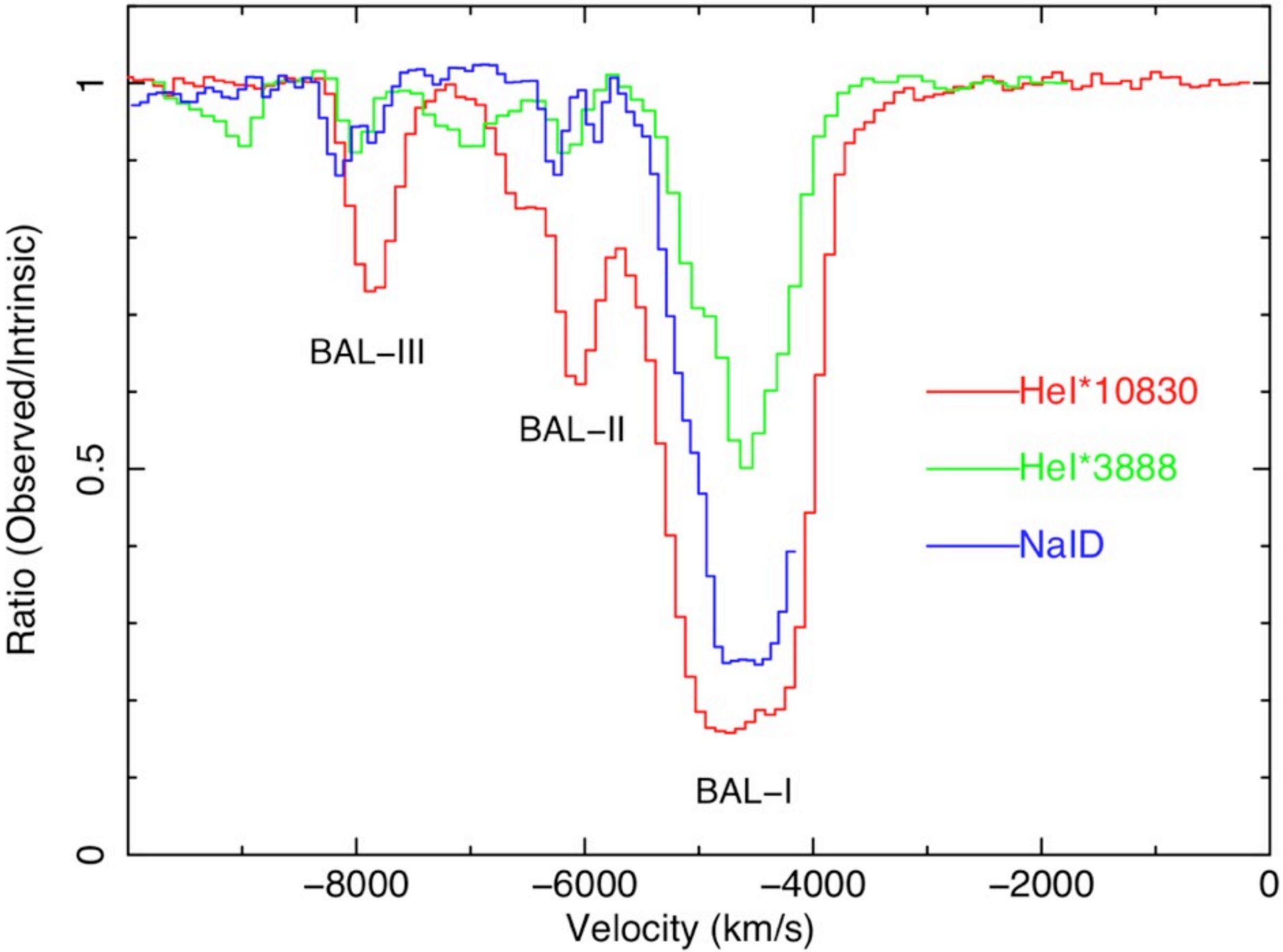
- HeI*3889 Selected BALQSOs 0.5<z<0.6
- 18 objects
- Observed using LBT Lucifer, Gemini GNIRS, KPNO 4m RC Spectrograph, and MDM 2.4m CCDS
- *Systematic* study of covering fraction and HeI* column density

Mrk 231

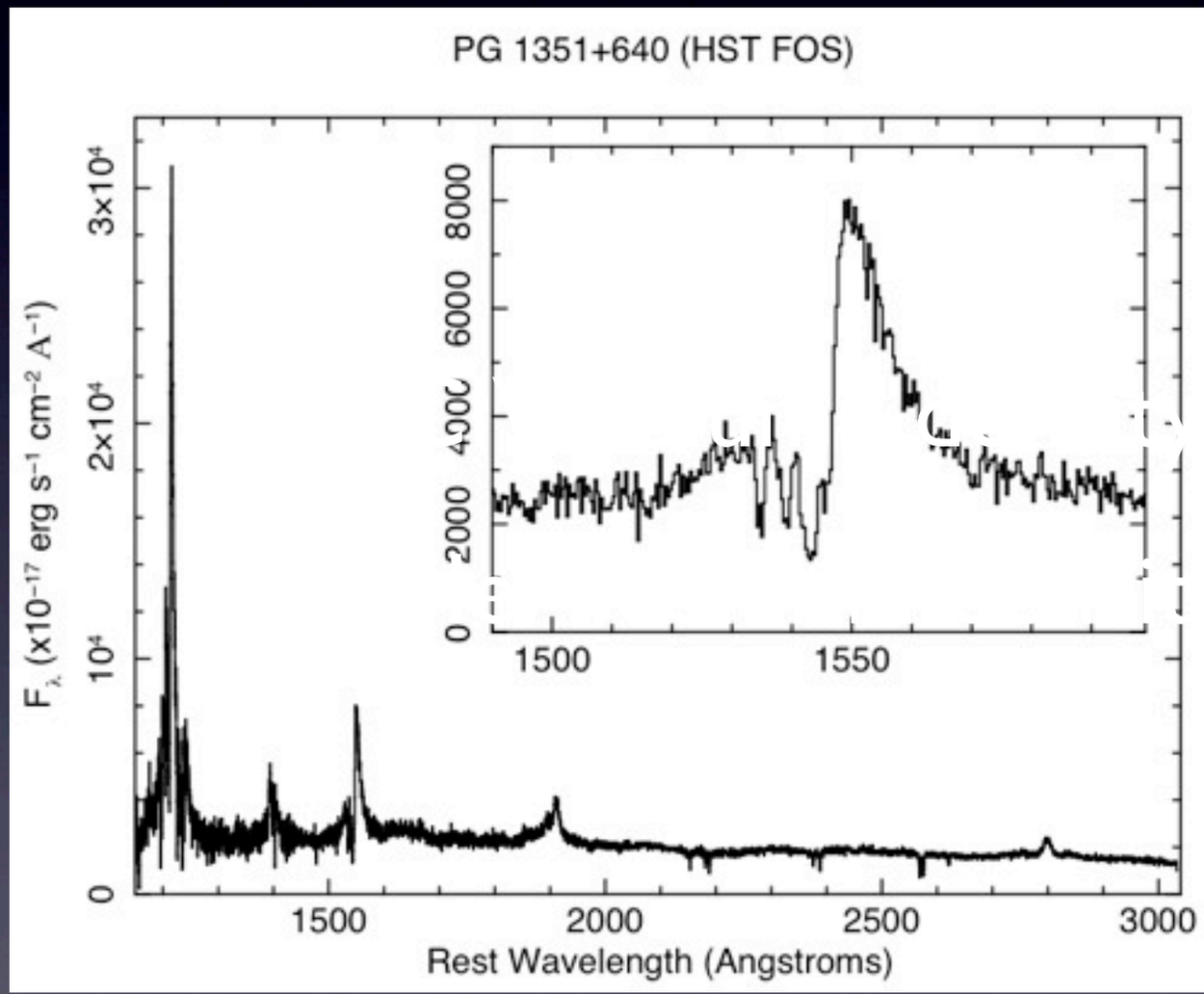

Mrk 231 (KPNO 4m)
F_λ (x10^{-17} erg s^{-1} cm^{-2} A^{-1})
0
500
1000
1500
3500
4000
4500
5000
5500
Rest Wavelength (Angstroms)

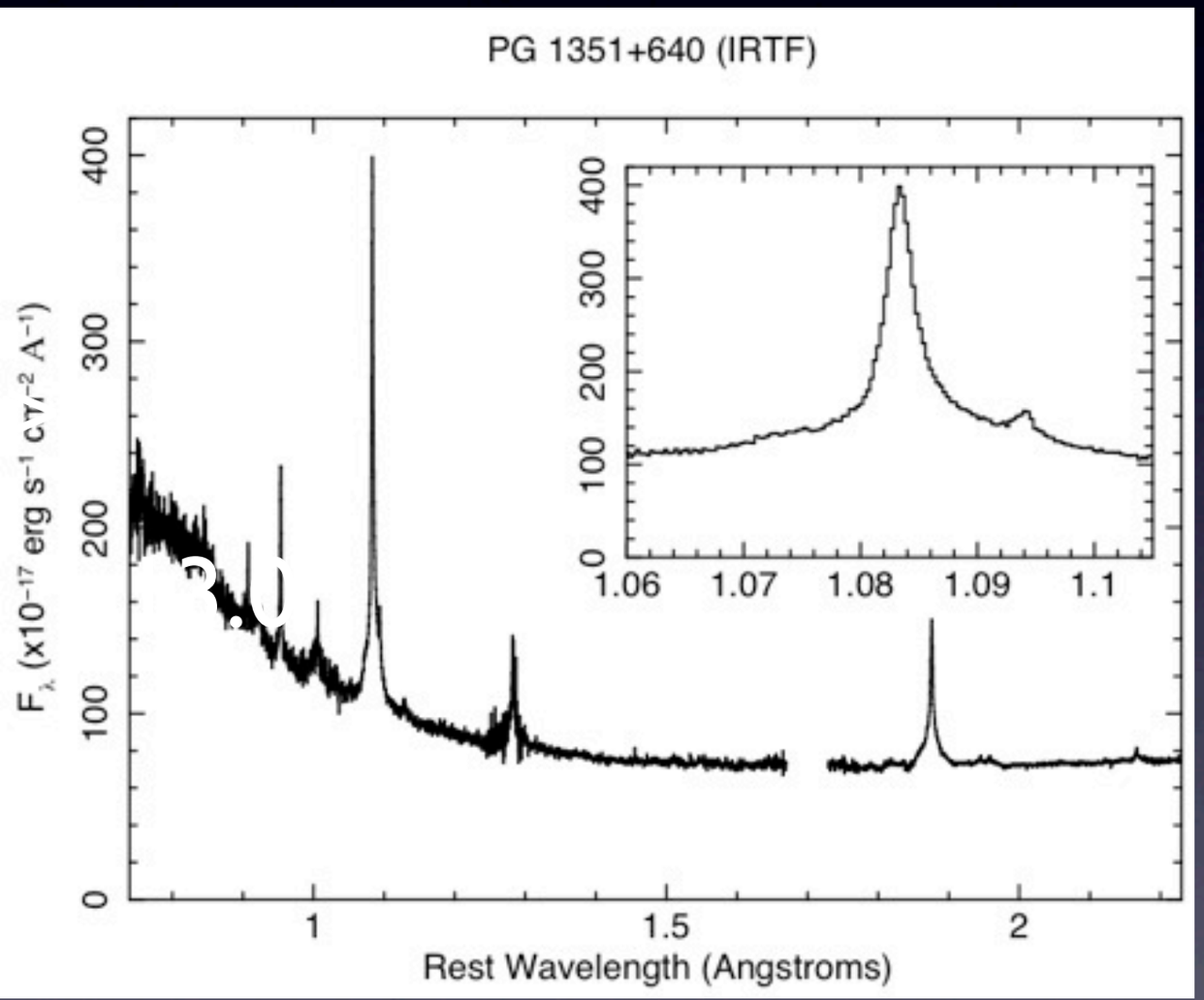

Mrk 231 (IRTF)
F_λ (x10^{-17} erg s^{-1} cm^{-2} A^{-1})
0
500
1000
1500
1
1.5
2
Rest Wavelength (microns)

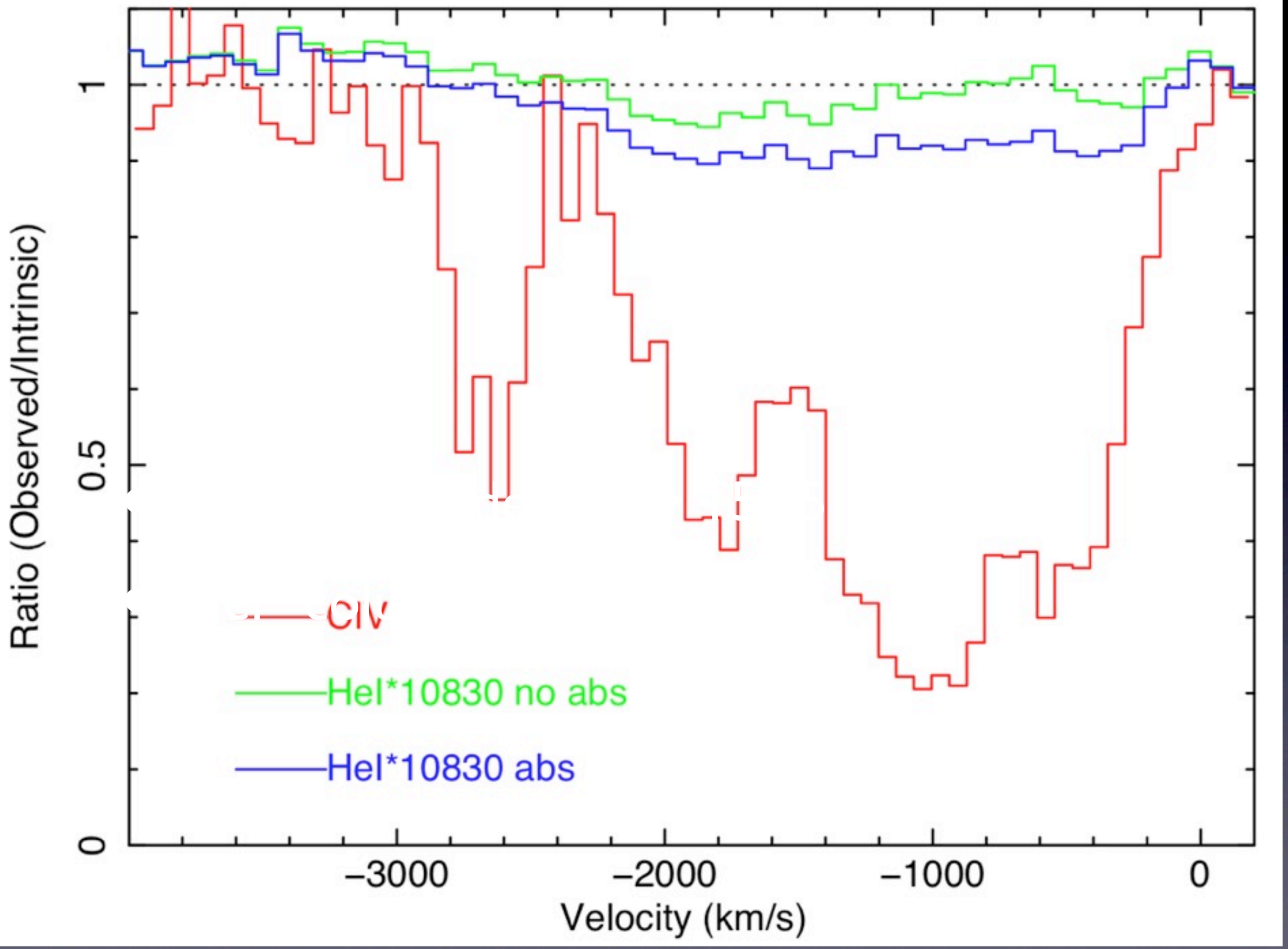

Ratio (Observed/Intrinsic)
1
0.5
0
BAL–III
BAL–II
BAL–I
HeI*10830
HeI*3888
–8000
–6000
–4000
–2000
0
Velocity (km/s)


Ratio (Observed/Intrinsic)
1
0.5
0
BAL–III
BAL–II
BAL–I
HeI*10830
HeI*3888
NaID
–8000
–6000
–4000
–2000
0
Velocity (km/s)

PG 1351+640

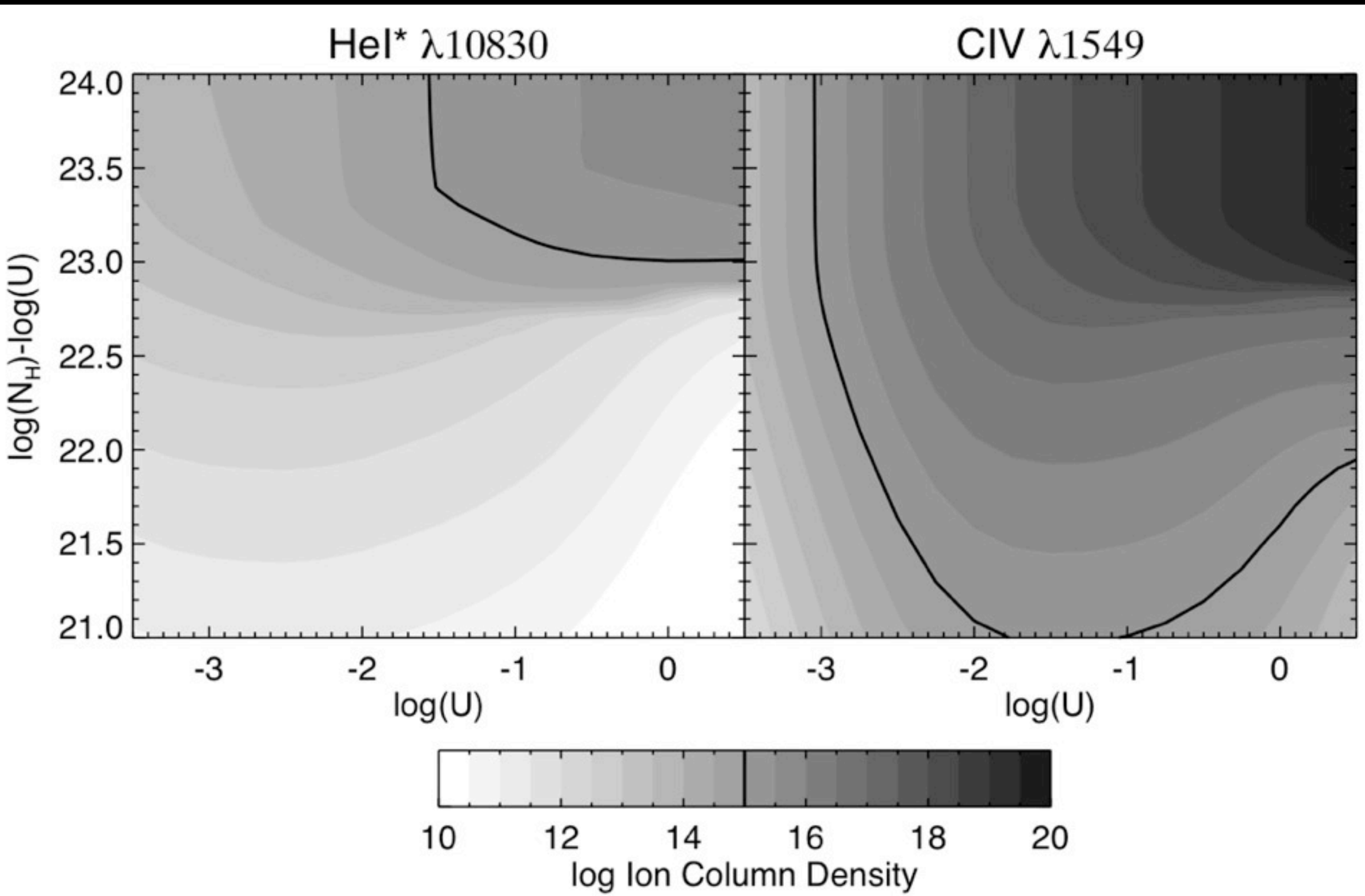

PG 1351+640 (HST FOS)
F_λ (x10^{-17} erg s^{-1} cm^{-2} A^{-1})
Rest Wavelength (Angstroms)
0
10^4
2×10^4
3×10^4
1500
2000
2500
3000
0
2000
4000
6000
8000
1500
1550


PG 1351+640 (IRTF)
F_λ (x10^{-17} erg s^{-1} cm^{-2} A^{-1})
Rest Wavelength (Angstroms)
0
100
200
300
400
1
1.5
2
0
100
200
300
400
1.06
1.07
1.08
1.09
1.1

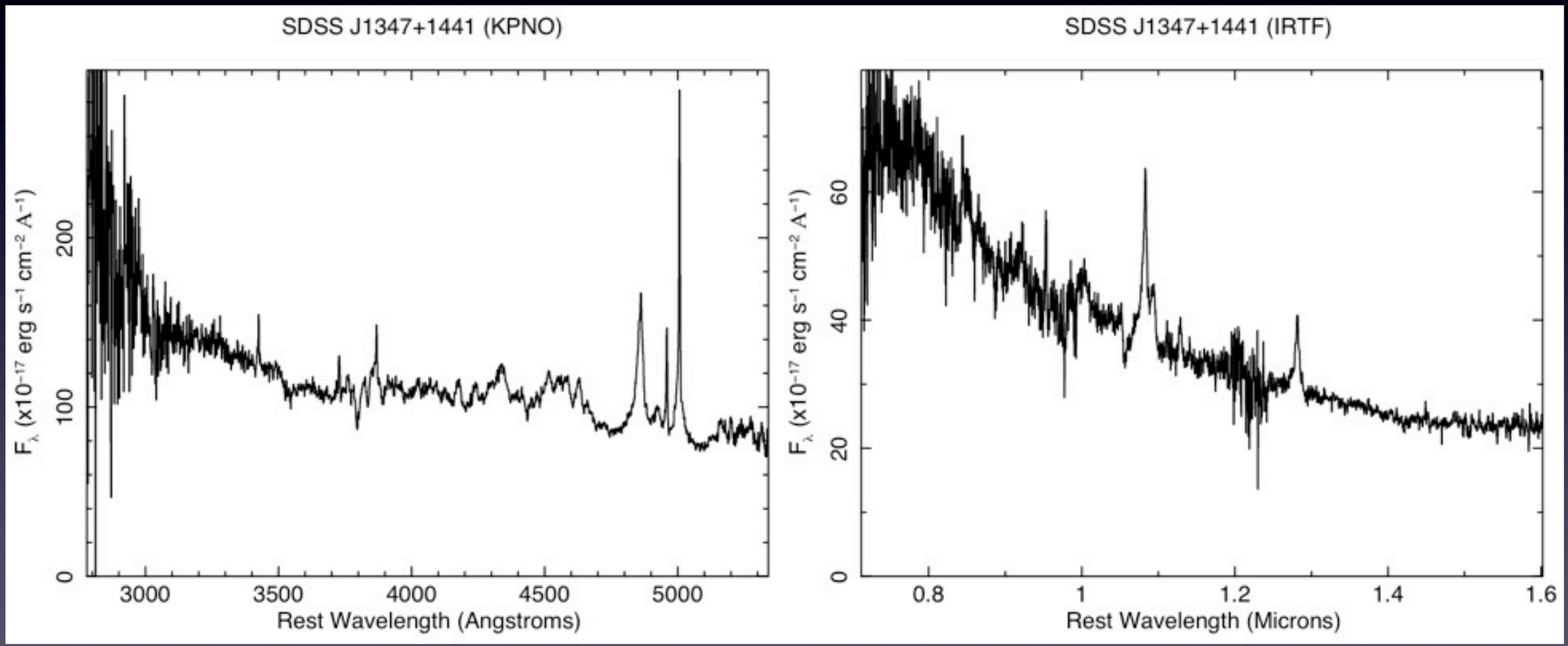

Ratio (Observed/Intrinsic)
1
0.5
0
CIV
HeI*10830 no abs
HeI*10830 abs
−3000
−2000
−1000
0
Velocity (km/s)

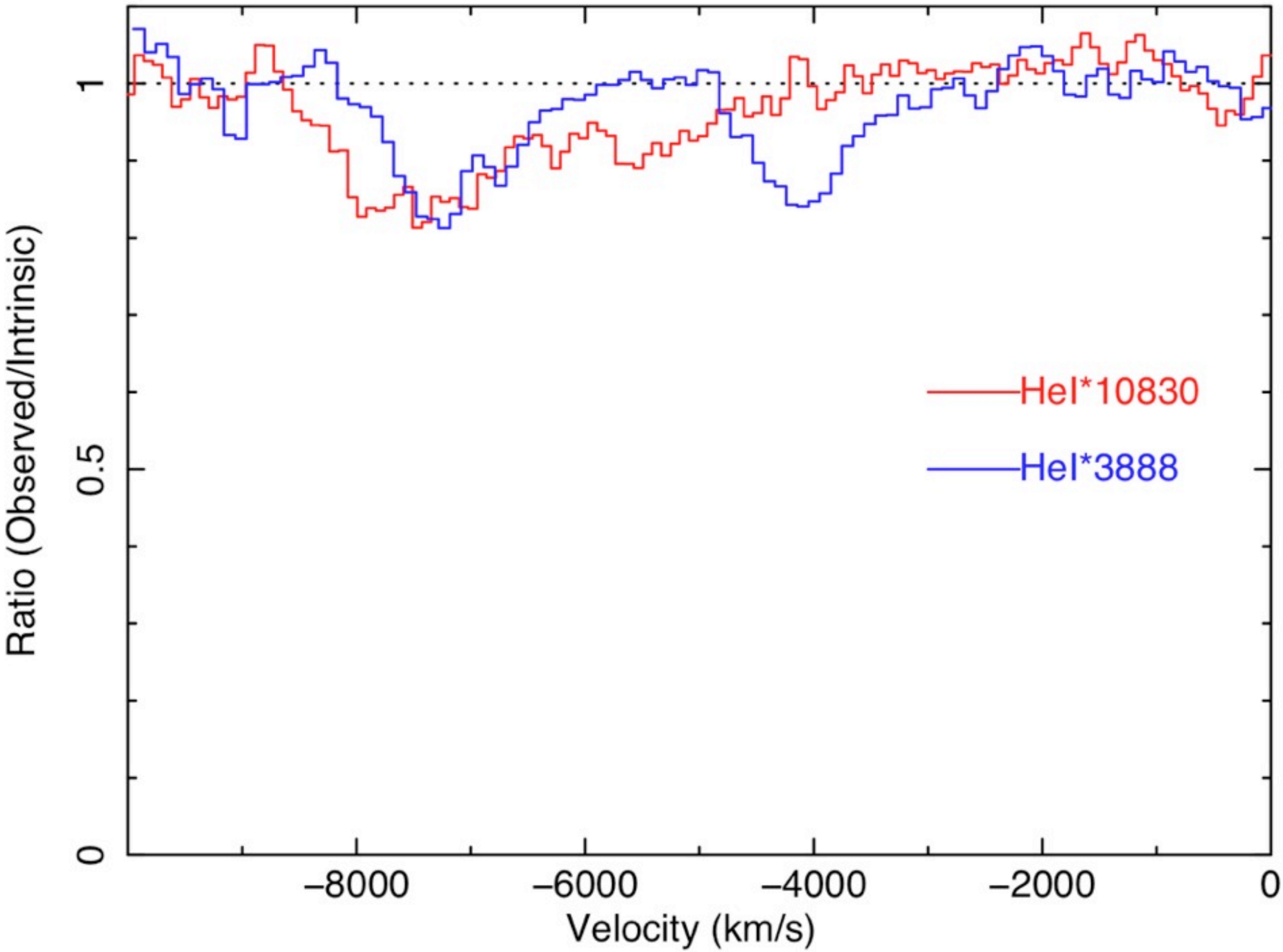
PG 1351+640

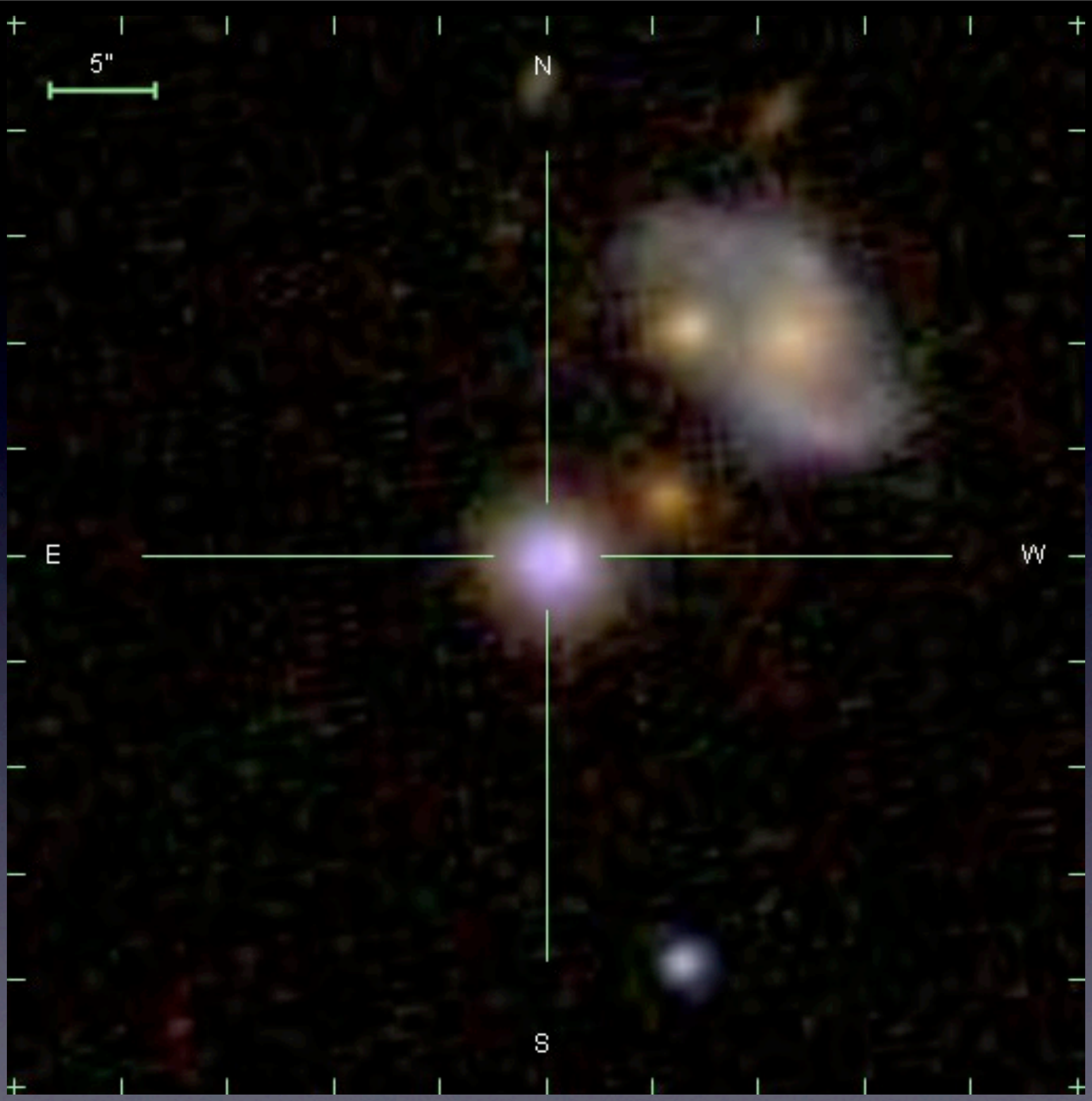
- CIV column density > 15.25
- HeI* column density ~ 13.0


HeI* λ10830
CIV λ1549
log(N_H)-log(U)
24.0
23.5
23.0
22.5
22.0
21.5
21.0
-3
-2
-1
0
log(U)
log(U)
10
12
14
16
18
20
log Ion Column Density

SDSS J1347+1441




Ratio (Observed/Intrinsic)
1
0.5
0
HeI*10830
HeI*3888
−8000
−6000
−4000
−2000
0
Velocity (km/s)


5"
N
E
W
S

Conclusions

- We discovered HeI*λ10830 in FBQS J1151+3822
  - Using HeI*λ3889, we measure the covering fraction and optical depth
  - Cloudy models yield equivalent hydrogen column; acceleration modeling yields further constraints
  - New MgII observation constraints results further
- We find that HeI* is an excellent probe of high column densities, comparable to PV
- Two additional samples will yield information about HeI* absorption in general

Junior Faculty Position in Astronomy/Astrophysics, University of Oklahoma - JRID40479

The Homer L. Dodge Department of Physics and Astronomy invites applications for a tenure-track position at the Assistant Professor level to begin in Fall 2012. Applicants must hold a doctoral degree and must have the ability to teach effectively at both undergraduate and graduate levels. The potential to initiate a strong research program is essential. Important assets include post-doctoral experience and a coherent research plan capable of attracting external funding. Current research interests of our astronomy and astrophysics group include supernovae, astrophysical atmospheres, stellar and nebular abundances, galactic chemical evolution, AGNs, cosmology, gravitational lensing and galaxy clusters, and exoplanets and debris disks. For further information about our department see http://www.nhn.ou.edu [2]. To apply please send application materials electronically to Dr. Karen Leighly, Astrophysics Search Committee Chair, at astrosearch@nhn.ou.edu [3]. Alternatively, application materials may be sent by regular mail to Dr. Leighly in care of the Homer L. Dodge Department of Physics & Astronomy, University of Oklahoma, Norman, OK 73019. Initial screening of applicants will begin on December 1, 2011, and continue until the position is filled. Complete applications will consist of a vitae, a publication list, a description of research and teaching goals and interests, and three confidential letters of recommendation sent separately. The University of Oklahoma is an Affirmative Action/Equal Opportunity employer and encourages diversity in the workplace.